EFFECT OF IMPULSE VOLTAGE ON SOLID INSULATION

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

By

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CERTIFICATE

This is to certify that the draft report/thesis titled "**Effect of impulse voltage on solid insulation**", submitted to the National Institute of Technology, Rourkela by **Mr.Ashish Kumar Singh,Roll No**: **109EE0602 and Mr.S.ChandraPrakash,Roll No. 109EE0655** for the award of Bachelor of Technologyin Electrical Engineering, is a bonafide record of research work carried out by him under my supervision and guidance.

The candidate has fulfilled all the prescribed requirements.

The draft report/thesis which is based on candidate's own work, has not submitted elsewhere for a degree/diploma.

In my opinion, the draft report/thesis is of standard required for the award of a Bachelor of Technologyin Electrical Engineering.

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ABSTRACT

One of the main problems of the high voltage engineering is the degradation of the insulation of the solid insulating material.It has been revealed through the several researches and studies that the high voltage power equipment are directly and mainly subjected with the spark over voltage caused by impulse voltage like lightening strokes and switching action.The sphere-sphere electrode arrangements are mainly used for the measurement of the peak values of the high voltages as adopted by the IEC and IEEE. Generally in the electrical power equipment, the standard sphere gaps are widely used. The effect of the impulse voltage on different insulations like Nomex,Lather Minilex,White Minilex and Glass Cloth has been studied.To study and observe the effect on insulation of the solid material due to breakdown mechanism, the insulation samples are collected after the application of the impulse voltage test and analysis is done with the help of scanning electron microscope(SEM).A standard sphere of 25cm in diameter is used to measure the effect of impulse voltage. Finally the experimental data is generated and compared with the theoretical and the graphical interpretation is done.

Hence the determination of the breakdown voltage of various insulating material gives a major area of interest to the electrical engineers and in particular to the high voltage engineers.Therefore,the possibility of developing solid insulating materials with excellent breakdown strength is viable through study and research.The few basic and important topics affecting the breakdown and study of different composite insulating materials are reviewed.

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ACRONYMS AND ABBREVIATIONS

SEM	Scanning Electron Microscope
ε_0	Permittivity of free space
ε_r	Relative permittivity
V	Voltage
HV	High voltage
V_{BD}	Breakdown voltage

CHAPTER 1

THESIS OVERVIEW

CHAPTER-1

THESIS OVERVIEW

1.1Introduction

Rapid growth over recent years in the power sector of the country has given the opportunity to the power engineers to protect the power equipment during their operating life for reliable operation. Therefore it becomes necessary for the todays electrical engineers to know various types of solid insulations and their properties in order to economize the cost applications and keeping safety considerations on the other hand. One of the main problems of the high voltage engineering is the degradation of the insulation of the solid insulating material. It has been revealed through the several research and studies. As the high voltage power equipment are directly and mainly subjected with the spark over voltage caused by impulse voltage like lightening strokes and switching action. The sphere-sphere electrode arrangements are mainly used for the measurement of the peak values of the high voltages as adopted by the IEC and IEEE. Generally in the electrical power equipment, the standard sphere gaps are widely used. The effect of the impulse voltage on different insulations like Nomex,Lather Minilex,White Minilex and Glass Cloth has been studied. To study and observe the effect on insulation of the solid material due to breakdown mechanism, the insulation samples are collected after the application of the impulse voltage test and analysis is done with the help of scanning electron microscope (SEM).A standard sphere of 25cm in diameter is used to measure the effect of impulse voltage. Finally the experimental data is generated and compared with the theoretical and the graphical interpretation is done.

1.2 Objective

The objective of the present thesis work is to find the effect of impulse voltage on solid insulation material like Nomex Paper, Glass Cloth, White minilex Paper and Lather minilex Paper. The Sphere-sphere gap geometry is used for the conduction of experiment which is available in the high voltage laboratory of NIT Rourkela. The knowledge of the breakdown voltage of the various solid insulating materials helps us to determine the insulation type and their strength inorder to protect the equipment to perform efficiently and avoid failure.

1.3 Literature review

The book written on High Voltage Engineering by C.L Wadhwa has helped us to get basic idea on the impulse voltage[1]. E.Kuffel, W.SZeangle and J.Kuffel have published book on High Voltage Engineering Fundamentals for getting basic fundamental for our thesis work[2].Author M.S Naidu and V. Kamaraju have published book on High Voltage Engineering which helped in assimilating our work[3].C.Forthergill presented paper on the Ageing, space charge and nanodielectrics[4].A short method of estimating lifetime of propylene film using steep stress test has been conducted by P.Cygan, W. Khechen and R.Laghari[5].The residual a.c breakdown voltage of 6.6 kV dry –cured XPLE power cable under wet – accelerated aging test has been proposed by T.Hashizume, C.Shinoda, K.Nakamura, M.Hotta and T.Tani[6].U.Riechert,M.Eberhardt, J.Kindersberger and J.Speek presented paper on the breakdown behavior of polyethylene at d.c voltage stress[8].P. Basappa, S.Jang and J.Kim have done work the electrical breakdown studies on electro active paper[9]. S. Grzybowski, E.A Feilat, P. Knight and L. Doriott have presented paper on the breakdown voltage behavior of thermoplastics at d.c and a.c voltages[10].The breakdown mechanism of solid insulating material like polyethylene and nanocomposite is done by various researchers[11-13].K.

Elanseralathan, J. Thomas ans G.R Nagabhusana have done the work on breakdown solid insulating materials under high frequency high voltage stress[14]. The work on determination of aging model constants under high frequency and high electric fields has been done by W. Khachen and J.R Laghari[15]. J.H Mason has presented the work on effect of thickness and area on the electric strength of polymers[16].Breakdown voltage behavior of leatherite paper with or without void is shown in paper of S.Ghosh and N.K Kishore[17].M.G Dakins has proposed breakdown strength of silicone rubber[18].Electrical breakdown due to discharges on different types of insulation has been proposed by C. Laurent, C. Mayoux and A.Sergeant[21]. G.L Atkinson and W.R Thomas presented paper on an epoxy paper insulation system for high voltage applications [24]. P.H.F Morshius has done work on the degradation of solid dielectrics due to internal partial discharges [29]. K.S Naidu, S.K Jain, V.N Maller and P.Satyanarayan have conducted studies on the partial discharges study non uniform fields with insulating barrier [31-33].

1.4 ORGANIZATION OF THE THESIS

The thesis has been organized into siximportant chapters in which each chapter has its own way of describing and analyzing the fundamentals of the work followed by theoretical and experimental results which reveals the lubricity of the work.

Chapter 1 : The first chapter deals with basic introduction, objective of the thesis and literature review on the Effect of Impulse Voltage on solid insulation. It also includes the organization of the thesis.

Chapter 2 : In this chapter the basic definition of the Impulse Voltage is described and the factors affecting the breakdown voltage of solid insulating material is studied. The basic theoretical study of the Impulse Voltage Generator is carried out and the breakdown mechanism in solid dielectrics is studied. It also describes the different class of insulators.

Chapter 3 : This chapter deals with experimental setup for the breakdown voltage of solid insulating material using standard sphere-sphere electrode arrangement. In this chapter the apparatus required for the measurement of the effect of impulse voltage on solid insulating material and the description of the apparatus used is discussed.

Chapter 4 : This chapter deals with experimental procedures and observations. It covers the task of sample preparation of the solid insulating material which is commercially available in the market. The measurement of the breakdown voltage of the insulating sheets, monitoring of the state of solid insulating material and interpretation of the SEM images is done in this chapter.

Chapter 5 : This chapter deals with the results and discussion of the research work. The graph is plotted for the characteristic performance of the insulating sheets under various parameters such as thickness of the insulating sheet and gap geometry of the electrodes.

Chapter 6 : Finally, in this chapter the conclusion of the project work is included and future scope of the work for the advancement of technology is discussed.

CHAPTER 2

INTRODUCTION AND BREAKDOWN VOLTAGE OF SOLID INSULATING MATERIAL

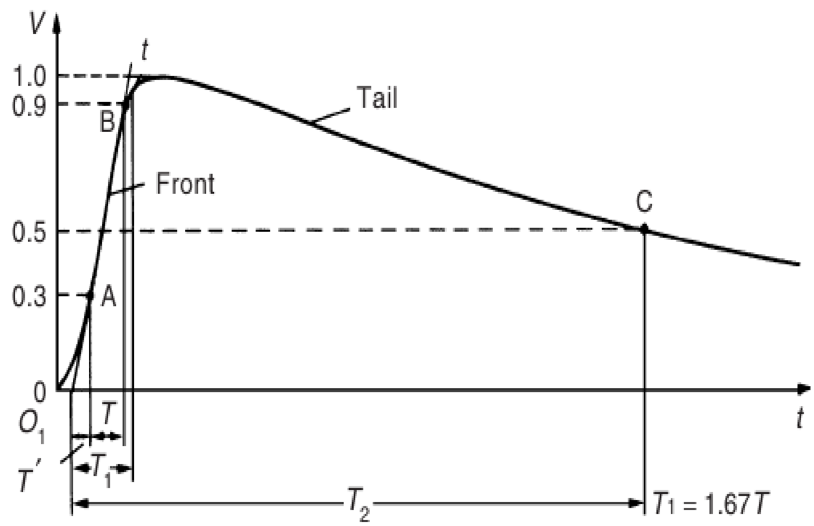
CHAPTER-2

INTRODUCTION AND BREAKDOWN VOLTAGE OF SOLID INSULATING MATERIAL

2.1IMPULSE VOLTAGE

An impulse voltage is a unidirectional voltage, which, rises rapidly to a maximum value and falls to zero instantly. The maximum value is called the peak value of the impulse voltage. The impulse voltage is specified by this value. Small oscillations which have amplitude less than 5% of the peal value of impulse voltage are tolerated. A mean curve should be considered in case of oscillations in the wave shape. Full impulse voltage can be defined as an impulse voltage which develops without causing flash over or puncture.

Chopped impulse voltage can be defined as flash over or puncture occur which causes a sudden collapse of the impulse voltage. A full impulse voltage is characterized by its peak value and by the wave front and wave tail, which is its two time interval. The wave front time of an impulse wave is defined as the time taken by the wave to reach to its maximum value starting from zero value. Generally it is difficult to identify the start and peak points of the impulse wave and so the wave front time is specified as 1.25 times ($t_2 – t_1$), where t_2 is defined as the time for the impulse wave to reach its 90% of the peak value and t_1 defined as the time to reach 10% of its peak value. Since ($t_2 – t_1$) represents 80% of the wave front time, to give total wave front time, it is multiplied by 1.25 to give the total wave front time.. The point where the line CB intersects the time axis is known to be the nominal starting point of the impulse wave.The nominal wave tail time is the point on the wave tail where the voltage is 50% of the peak value and between the nominal starting point t_0 i.e. wave fail time is expressed as ($t_3 – t_0$)[1].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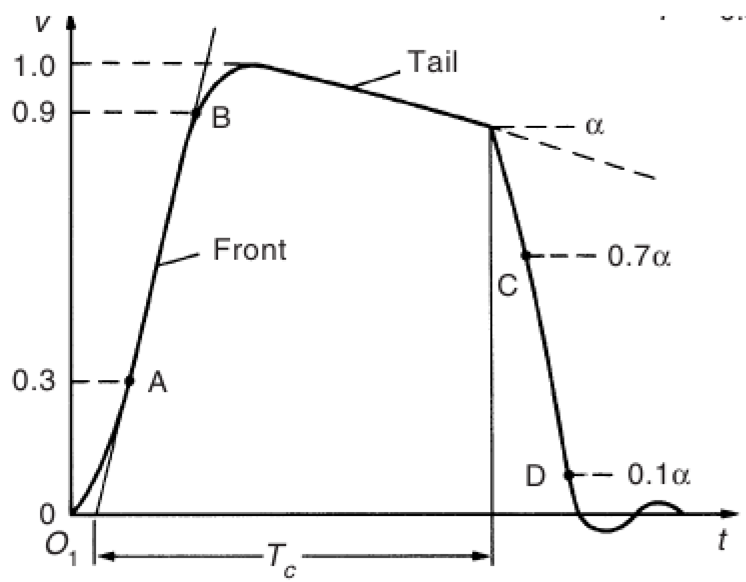
(a)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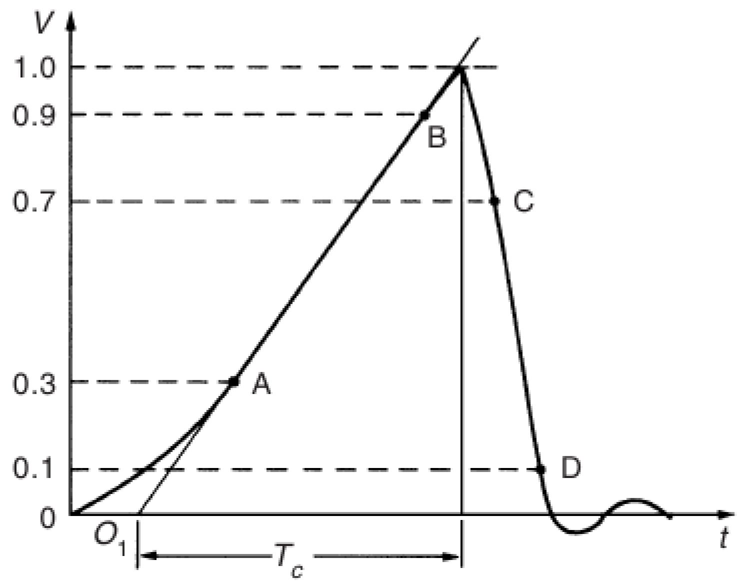


(c)

FIG 2.1(a)Full impulse voltage(b)Chopped on the tail impulse voltage(c)Chopped on front impulse voltage.T_1:Front time.T_2:Time to half value.T_C: Time to chopping.O_1:Virtual origin .

2.1.1 IMPULSE FLASH OVER VOLTAGE

Whenever an impulse voltage is applied to an insulating medium of different thickness, it is not certain that the flash over may or may not take place. If out of a total ten applications of impulse voltage about 5 of them flash over then the probability of flash over of the impulse voltage is 50%. However, it is to be noted that the flash over occurs at an instant subsequent to the attainment of the peak value. The flash over also depends upon the polarity, duration of wave front and wave tails of the applied impulse voltages. The impulse flash over

Voltage for flash over on the wave front is the value of the impulse voltage at the instant of flash over on the wave front. If the flash over occurs more than 50% of the number of applications, it is defined as impulse flash over voltage in excess of 50%.

The impulse puncture voltage can be defined as the peak value of the impulse voltage which causes puncture of any material like solid insulations when puncture is on the wave tail and is the value of the voltage at the instant when puncture occurs on the wave front. Impulse ratio for the flash over is defined as the ratio of impulse flash over voltage to the peak value of power frequency flash over voltage. Impulse ratio for flash over is not constant for any particular object but depends on the polarity and the shape of the impulse voltage. The impulse ratio for puncture is defined as the ratio of the impulse puncture voltage to the peak value of the power frequency of the puncture voltage [1-3].

2.2IMPULSE VOLTAGE GENERATOR

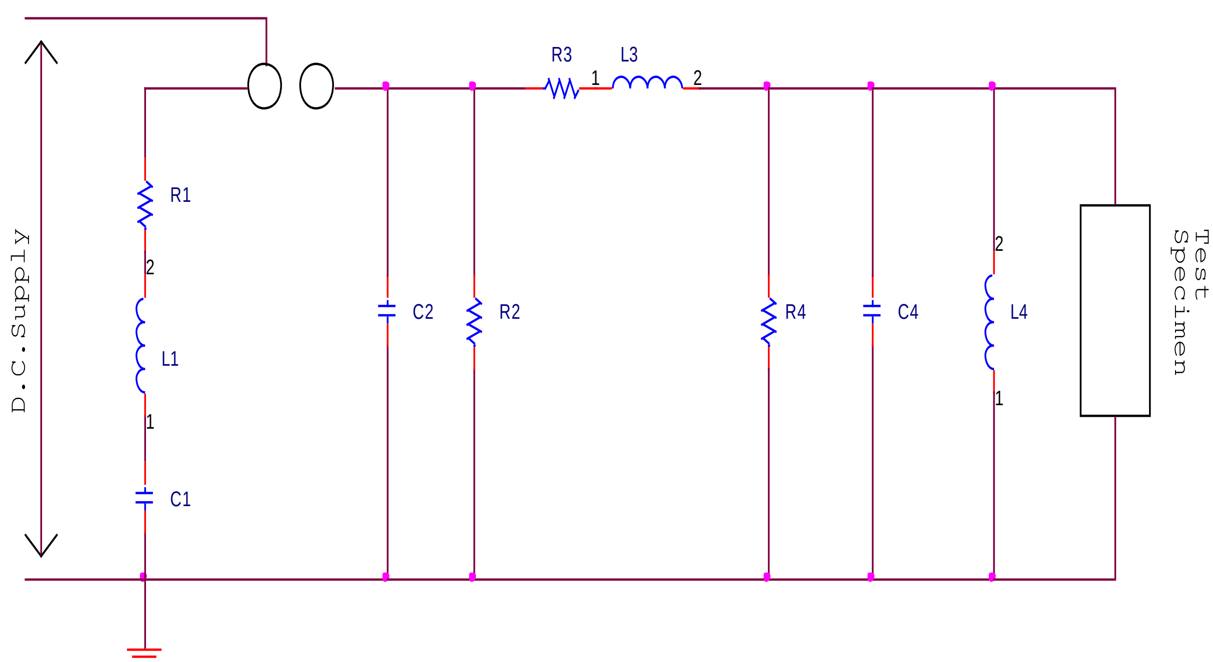


FIG 2.2 Impulse voltage generator.

The figure shows the exact equivalent circuit of a single stage impulse voltage generator along with the typical load.C_1 is the capacitance of the generator which is charged a DC source to a suitable voltage which causes discharge through the sphere gap. The capacitance C_1 may consists of a single capacitance where the generator is known as the single stage impulse voltage generator. When C_1 is the total capacitance of group of capacitors charged in parallel and discharged in series then it is known as multi stage generator. L_1 is the inductance of the generator and leads connecting the generator to the discharge circuit and is usually kept small. The resistance R_1 consists of series resistance of the capacitances and leads to additional lumped resistance inserted within the generator which is for damping purpose and for output waveform control.L_3 and R_3 are the external elements which are connected at the generator terminal for waveform control. The function of R_2 and R_4 is to control the duration of the wave. Also R_4 serves the purpose of a potential divider when a CRO is used for measurement purposes.C_2 and C_4 represent the capacitances to earth of the high voltage components and leads.C_4 also contains the capacitance of the test object and of any other load capacitance which is required for producing the required wave shape. L_4 represents the inductance of the test object and can affect the wave shape considerably. Basically for practical reasons one terminal of the impulse voltage generator is grounded solidly. The polarity of the output voltage is changed by changing the polarity of D.C. charging voltage [2].

For the evaluation of various impulse voltage circuit elements, its analysis using the equivalent circuit is quite important and complex. To simplified and practical forms of impulse voltage generator are shown in figures.

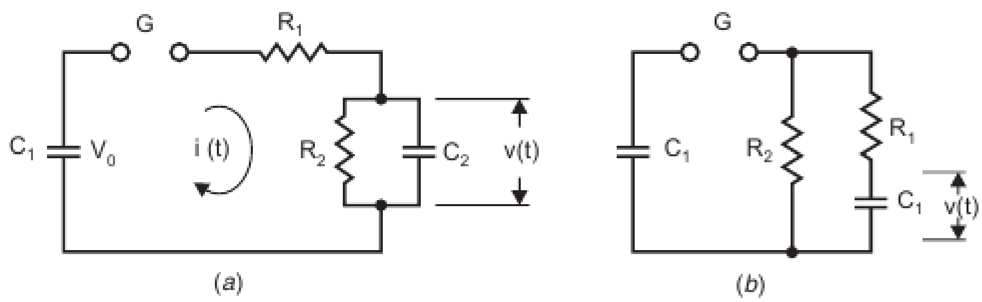


FIG 2.3 Simplified equivalent circuit of an impulse voltage generator.

The two circuits shown are widely used. They differ only in the position of the wave tail control resistance R_2.When R_2 is on the load side of the R_1 as shown in the figure (a) the two resistances forms a potential divider which reduces the output voltage but when R_2 is on the generator side of R_1 as shown in figure (b) this particular loss of output voltage is absent.

The impulse capacitor C_1 is charged through a charging resistance to a DC voltage V_0 which is discharged by flashing over the switching gap with the suitable value of pulse. Across the load capacitance C_2 the desired impulse voltage appears. The shape of the output impulse voltage is determined by the value of the circuit elements.

2.3 BREAKDOWN OF SOLID INSULATING MATERIAL

Solid insulation forms an important and an integral part of high voltage engineering. The solid insulating materials insulate conductors from one another. Therefore the knowledge and study of the failure mechanisms of solid insulating mechanisms under various electric and voltage stresses is of great importance. However numerous investigations and research on breakdown of solids have been done and a number of theories have been given to explain the breakdown processes in solids still the state of knowledge in this field is very inconclusive. The breakdown in solid insulation can be broadly categorized as [3].

(a) Intrinsic or ionic breakdown

(b) Electromechanical breakdown

(c) Failure due to treeing and tracking

(d) Thermal breakdown

(e) Electrochemical breakdown

(f) Breakdown due to internal discharges

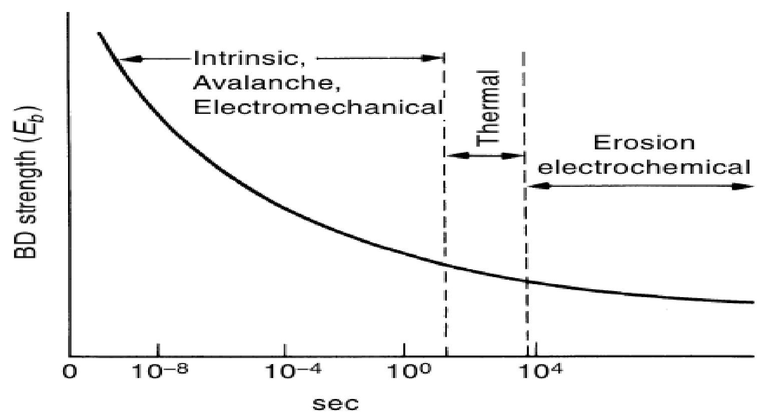


Fig 2.4 Variation of breakdown strength with time after application of voltage.

Fothergill very clearly showed the between the breakdown and degradation of a solid insulating material. According to him, the breakdown phenomenon that is sudden and catastrophic and the insulation of the solid insulating material cannot withstand the service voltage which leads to the breakdown. The degradation of solid insulating material, on the other hand takes place over a period of time. It increases the probability of the. Breakdown process and decreases the breakdown voltage of material. The erosion and pit formation are important in the degradation process and are followed by tree formation and final dielectric failure. The degradation process after a long period of hours and weeks, leads to breakdown. Well-designed insulation systems, operated within the scope and aim of design parameters, do not break or degrade easily. Both these processes are irreversible. Table 2.1 shows some of the differences between breakdown degradation for a solid insulating material [4].

Table 2.1 Shows the variation of breakdown strength on application of voltage with time.

FEATURES	BREAKDOWN	DEGRADATION
Effect	Catastrophic insulation cannot be used afterwards.	Leads to breakdown, reduces breakdown voltage
Speed	Fast occurs<<1s	Hours and years
Evidence	Direct observation by eye	Observation would require microscope
Examples	Intrinsic,thermal,electromechanical,electrochemical,partial discharge in cavities	Electrical trees, water trees

2.4 FACTORS AFFECTING BREAKDOWN OF SOLID INSULATING MATERIALS

The breakdown of solid insulating materials depends on the following factors:

2.4.1 NATURE OF WAVEFORM

The breakdown voltage of solid insulating materials largely depends on the nature of the voltage waveform applied to it that is DC, AC and impulse [5-12].

2.4.2 FREQUENCY

The variation of frequency on solid insulating material has an important role to play in affecting the breakdown voltage of solid dielectrics. At higher frequency, the breakdown voltage is much lower than the breakdown voltage at 50 Hz [13-14].

2.4.3 AGEING

The breakdown voltage of solid insulating material decreases with the ageing of the dielectric. The deterioration process is due to acceleration of partial discharges and heat which is build up in the voids and micro cavities of the solid insulating materials when frequency is increased. The constant n of the power model remains constant when frequency is increased. The inverse power model is given by [13].

$$L=k*V^{-n} \qquad (2.1)$$

Where L=time to failure

V=applied voltage

K and n are constants determined from the experimental data

2.4.4 THICKNESS OF THE DIELECTRIC MATERIAL

The thickness of the dielectric material clearly affects the breakdown voltage. The short time electric strength is more dependent on the thickness than the area of the samples [16].Table 2.2 shows the effect of the change in thickness of the breakdown voltage of the solid insulating material like polyethylene [16-17].

Table 2.2 Variation of breakdown voltage of polyethylene with thickness [16]

THICKNESS(mm)	BREAKDOWN VOLTAGE(air)(V/µm)
3.1	33
1.5	28
0.18	72
0.09	122

2.4.5 ELECTRODE GAP SPACING

The breakdown voltage strength of the solid insulating material decreases with the increase in gap spacing [18].

2.4.6 PARTIAL DISCHARGE IN CAVITIES

The partial discharge study has been an important field of solid insulation over past few years. The main sources of partial discharge are the voids within the solid insulating materials. These voids are gas filled and can result from many causes such as air leaking into the mold during curing. If the voltage between the electrodes is increased to the level that the field within the Voids goes above the breakdown strength of the gas, a partial discharge can take place. The time taken for the breakdown to actually occur depends on the size of the cavity and the applied voltage [19-29].

2.4.7 THICKNESS AND RELATIVE PERMITTIVITY OF THE INSULATING MATERIAL

The authors have developed mathematical relationships between the breakdown voltage due to the partial discharge in the cavities and with the thickness and relative permittivity of the solid insulating materials. The brief description of these relationships is as follows [30-33].

1) Naidu has shown that breakdown voltage due to the partial discharge decreases with the increase in thickness of the material. It depends on the relative permittivity ε_r, dielectric strength of the air E_g, and the thickness of the material and the air gap length as

$$V=A*E_g\,(g+t/\varepsilon_r)^n \qquad (2.2)$$

Where A=0.9508 and n=0.3496 [31].

2)Mason and Dakin have shown that the breakdown due to the partial discharge depends on the thickness of the material and the relative permittivity, ε_r of the material as

$$V=k*(t/\varepsilon_r)^{0.46} \qquad (2.3)$$

Where k=0.2 [32-33].

2.4.8 SPHERE GAPS

The two adjacent metal spheres of equal diameters whose separation distance is constant form a sphere gap for the measurement of the peak value of either DC, AC or impulse voltages.If the duration of the peak region is not too short in time, the ability to respond to the peak values of voltages is governed by a short statistical time lag which is defined as the waiting time for an electron to appear and to initiate an electron avalanche and breakdown streamer. The limitation in gap distance of the sphere gaps provides a fairly homogenous field distribution so that no corona or pre-discharge appears before breakdown. The permanent presence of primary electrons within the regions of maximum field gradients to start avalanches within a short time is of great importance. The electric field distribution of the sphere gaps within the high field regions must be sufficiently controlled by the electrode geometry and the air density [2].

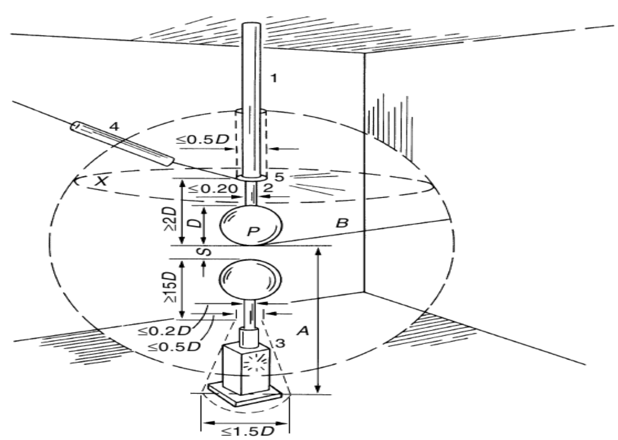


Fig 2.5 1.Insulating support. 2. Sphere shank. 3. Operating gear showing maximum dimensions. 4. High voltage connection with series resistor.5. Stress distributor. P=sparking point of high voltage sphere. A=height of P above ground plane. B=radius of space free from external structure.

2.5 TOLERANCES ON SIZE, SHAPE AND SURFACE OF SPHERES AND THEIR SHANKS

The spheres should be carefully made so that their surfaces are smooth and their curvature is uniform. The diameter should not differ by 2% from the nominal value. They should be free from surface irregularities in the region of the sparking point. The surfaces of the spheres near by the sparking point should be free from any trace of varnish, protective coating or grease. They should be clean and dry but not necessary to be polish. If the spheres become excessive rough or pitted in use they should be refinished or replaced. The sphere shanks should be reasonably in line and the shanks of the high voltage sphere should be free from corners or sharp edges, but the diameter of the shank should not exceed 0.2D over a length D [2].

2.6 SOLID INSULATING MATERIAL

There are various solid insulating material used in electronic and electrical equipment. Although this list does not covers all but focuses on some of the important solid insulating material. The various solid insulating materials can be categorized as:

CERAMIC: Ceramics are used to fabricate circuit boards, insulators and other components.The good thermal conductivity can be complemented by the good electrical insulating properties.

EPOXY/FIBREGLASS: This type of insulating material quite good because of its superior strength and excellent electrical properties even in humid condition.

GLASS: Glass insulation comes in a variety of forms including solid glass, fiber tapes, mats fiberglass sheets and mats, woven tubing and cloth, and various composites. High temperature Operation is an important feature of this type.

NOMEX: Nomex is a Dupont polyamide with working temperature range over220 degrees centigrade and with very high voltage breakdown. It is a very good choice for Standardization because it outperforms many other solid insulating materials.

SILICONE/FIBRE GLASS: It is a type of solid insulating material in which the glass cloth is impregnated with a silicone resin binder that makes an excellent laminate with good dielectric loss when it is kept dry.

PVC: Polyvinyl chloride is the most commonly used solid insulating material used. Most wiring is insulated with PVC including house wiring. They have superior strength and excellent resistance to heat.

2.7 CLASS OF INSULATORS

i) **Class-Y insulation**: Withstands a temperature of up to 90°C; typically made of cotton, silk or paper.

ii) **Class-A insulation**: Withstands a temperature of up to 105°C; reinforced Class-Y materials with impregnated varnish or insulation oil.

iii) **Class-E insulation**: Withstands a temperature of up to 120 degree centigrade.

iv) **Class-B insulation**: Withstands a temperature of up to 130°C. This has a form that inorganic material is hardened with adhesives. This is the first insulator using this structure.

v) **Class-F insulation**: Withstands a temperature of up to 155°C; for example, made of Class-B materials that are upgraded with adhesives, silicon, and alkyd-resin varnish of higher thermal endurance.

vi) **Class H insulation**: Withstands a temperature of up to 180°C; for example, made of inorganic material glued with silicone resin or adhesives of equivalent performance.

CHAPTER 3

EXPERIMENTAL SETUP FOR THE EFFECT OF IMPULSE VOLTAGE ON SOLID INSULATING MATERIAL USING SPHERE-SPHERE ELECTRODE ARRANGEMENT

CHAPTER 3

EXPERIMENTAL SETUP FOR THE EFFECT OF IMPULSE VOLTAGE ON SOLID INSULATING MATERIAL USING SPHERE-SPHERE ELECTRODE ARRANGEMENT

3.1 APPARATUS REQIURED FOR THE EFFECT OF IMPULSE VOLTAGE ON SOLID INSULATING MATERIAL

To conduct the effect of impulse voltage on solid insulating material using standard sphere-sphere electrode arrangement in high voltage engineering laboratory the following apparatus is used

(a) Haefely multitest control module type 273
(b) Impulse voltage generator
(c) Circuit breaker
(d) High voltage transformer
(e) High voltage filter
(f) Voltage divider
(g) Sphere-sphere arrangement

3.2 DESCRIPTION OF THE USED APPARATUS

The brief description of all used apparatus for impulse voltage testing on solid insulating material is discussed below:

(a) Control module

It allows comfortable and flexible control of the impulse generator system. The unit can be connected with impulse measurement device to form an integral control and measurement system. The unit supports manual as well as test sequence. The device is primarily intended for use in automated test bays, which are controlled by a host computer. Beside this the instrument can also be used for stand-alone impulse generators, which do not require embedded solutions.

Fig 3.1 Haefelymultitest set control module Type 273

(b) Medium Impulse voltage generator

It is used to generate impulse voltages simulating lighting strokes and switching surges .The state energy is 5 or 10 kJ. Maximum charging voltage is 3 MV. The basic system can be upgraded in various ways for the special tests and for the greater ease of operation. A number of additional circuits and components allow optimizing the impulse test system for tests on different kind of high voltage test objects. Also the internal inductance is the lowest.

Fig 3.2 Medium impulse voltage generator

(c) Circuit breaker

The duty of circuit breakers and fuses is to rapidly interrupt fault current. When a short circuit occurs on the power system, currents of the order of tens of thousands of Ampere flow. A fault on the power system is usually caused by failure or breakdown of the insulation of some equipment on the power system. Often the fault current is caused by air breakdown due to overvoltage's, typically caused by system disturbances by factors such as lightning. These discharges develop into arcs, providing a path for the power frequency follow current. The presence of these power frequency fault currents are detected by the protection relays and the output contacts of the relays energize the circuit breaker trip coils. The trip coils activate mechanisms that release stored energy (usually a charged spring) to force the contacts apart to interrupt the current. This is an onerous task and the arc quenching is assisted in various ways, depending on the type of circuit breaker. With AC circuit breakers arc interruption is assisted by the presence of current zero crossings. The interruption of DC arcs is more difficult.

(d) High voltage transformer

A transformer is a static device. It transfers electrical energy from one circuit to another circuit through inductively coupled conductors the transformer's coils. A varying current in primary winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic field through the secondary winding. This varying magnetic field induces a varying electromotive force (EMF) in the secondary winding. This effect is called mutual induction. In this arrangement high voltage step up transformer having power rating of 15 kVA, 400V/100kV is used which is shown in Fig. 3.2. As the voltage goes up, the current goes down by the same proportion.

Figure 3.3 High Voltage Transformer

(e) Voltage divider

Voltage divider is fast and has good response parameters. Therefore they are normally used for the measurements of full and front chopped lighting impulses or impulse voltage with steep wave fronts. The response time of the divider is in accordance with IEC 600060.

Resistive voltage dividers are used when an additional capacitance in the test circuit is not permissible due to the slowdown effect of the time rise. The voltage divider cannot be used as a load .This voltage divider cannot be used as a load capacitor for the impulse generator.

(f) High voltage filter

In high voltage power networks are suffered mainly with higher order harmonics in the supply, to reduce these harmonics high voltage filters are mostly used. Due to the higher order harmonics; increased losses, resonance problems between the inductive and capacitive parts of the power network, overloading of capacitors, leading to malfunctioning and premature aging, interference with telecommunications and computers, disturbances in ripple control systems and high currents in neutral conductors problems are occurred. These filters have several benefits like higher power factor, improved voltage stability and network losses, filtering of harmonics in the system, avoidance of resonance problems and amplification of electrical disturbances

.

(g) Sphere - Sphere electrode

Two electrode of spherical in shape which are identical are used for the measurement of the breakdown voltage of insulating sheet. The sphere electrodes are made of aluminum coated with nickel and air acts as the insulating medium. The sphere electrodes used for the experiment is vertically aligned. The top sphere electrode is connected to the HV connector whereas the down electrode is grounded. The used sphere electrode has the diameter of 25 cm each. Before conducting the experiment the two electrodes are cleaned so that the dust

Particles residing over the surface are cleaned. As the surface of the electrode is non-uniform, anon-uniform electric field is generated as we apply the high voltage between the sphere electrodes. A 50 Hz transformer with a power rating of 15 kVA and transformation ratio of 400V/100kV, the HV electrode is energized.

Fig 3.4 Sphere-Sphere Arrangement

CHAPTER 4

EXPERIMENTAL PROCEDURE AND OBSERVATIONS

CHAPTER-4

EXPERIMENTAL PROCEDURE AND OBSERVATIONS

As mentioned earlier the primary object of the present thesis work is to see the state of the various solid insulating materials under the effect of impulse voltage and its suitability for different application in power system application .In order to carry out above objective scanning electron microscope (SEM) is used. Breakdown voltage of various solid insulating materials is generated experimentally under the effect of impulse voltage. In addition the experimental data is graphically analyzed.

4.1 SAMPLE PREPARATION

In order to find the effect of impulse voltage on solid insulating material, four commercially available insulating sheets namely nomex, lather minilex, glass cloth and white minilex paper of different thickness are used. The variation of thickness of these insulating are as follows:

Nomex : 5 mm and 7mm (Grey in color)

Glass cloth: 5mm and 7 mm (Yellow in color)

Lather minilex: 5mm and 7mm (Brown in color)

White minilex: 5mm and 7mm (White in color)

Before testing the effect of impulse voltage on solid insulating sheets, the procedure was followed as laid down in ASTM handbook. This makes sure that the surface insulating sheet is clean and dry, since contamination of the insulating sheet with dust particles and moisture may affect the result.

4.2 MEASUREMENT OF THE BREAKDOWN VOLTAGE OF INSULATING SHEETS

Table 4.1 Breakdown voltage of Nomex insulating paper

S.NO	NAME OF INSULATING SHEET	THICKNESS (mm)	GAP GEOMETRY(cm)	BREAKKDOWN VOLTAGE(kV)
1.	Nomex	5	0.5	78.01
2.	Nomex	7	0.5	79.16
3.	Nomex	5	1	80.3
4.	Nomex	7	1	81.05

Table 4.2 Breakdown voltage of Lather minilex insulating paper

S.NO	NAME OF INSULATING SHEET	THICKNESS (mm)	GAP GEOMETRY (cm)	BREAKDOWN VOLTAGE(kV)
1.	Lather Minilex	5	0.5	78.01
2.	Lather Minilex	7	0.5	80.34
3.	Lather Minilex	5	1	78.01
4.	Lather Minilex	7	1	79.16

Table 4.3 Breakdown voltage of Glass cloth insulating paper

S.NO	NAME OF INSULATING SHEET	THICKNESS(mm)	GAP GEOMETRY (cm)	BREAKDOWN VOLTAGE
1.	Glass Cloth	5	0.5	76.85
2.	Glass Cloth	7	0.5	80.34
3.	Glass Cloth	5	1	76.85
4.	Glass Cloth	7	1	78.01

Table 4.4 Breakdown voltage of White minilex insulating paper

S.NO	NAME OF INSULATING SHEET	THICKNESS (mm)	GAP GEOMETRY (cm)	BREAKDOWN VOLTAGE(kV)
1.	White Minilex	5	0.5	72.19
2.	White Minilex	7	0.5	73.35
3.	White minilex	5	1	80.3
4.	White minilex	7	1	81.5

4.3 MONITORING OF THE STATE OF SOLID INSULATING MATERIALS

Apart from the generation of the breakdown voltage of the insulating sheets experimentally, the monitoring of the state of the insulating sheet is very important and challenging task. In order to monitor the state of the insulating sheet at various voltage stresses, scanning electron microscope (SEM) is utilized. The SEM was operated under low vacuum mode, in order to visualize and observe the sample, which otherwise would be difficult due excessive surface charging.

4.4 SCANNING ELECTRON MICROSCOPE (SEM)

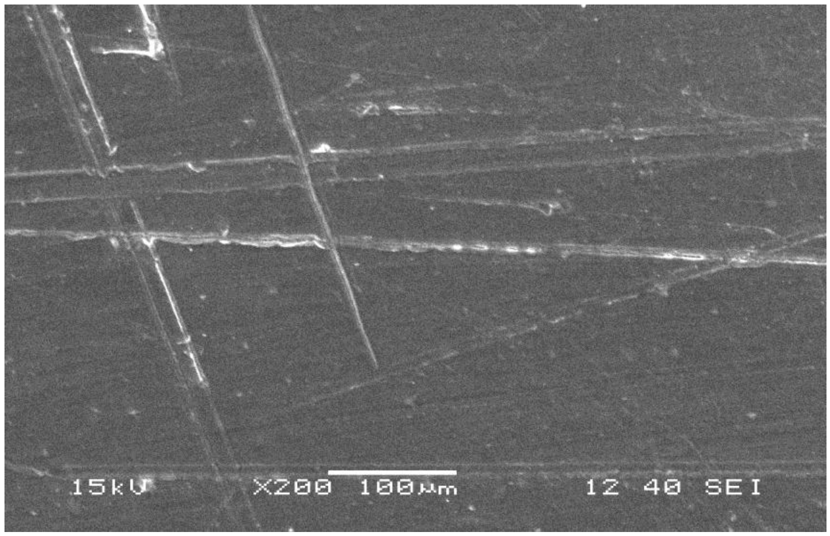
A scanning electron microscope (SEM) is a type of electron microscope that uses high energy beam of electrons in a raster scan pattern to find the image of the sample by scanning it. The electrons interact with the atoms that make up sample producing signals and that contain information about the samples composition, surface topography, and other properties such as electrical conductivity. Secondary electrons back scattered electrons (BSC), characteristic X-rays, Specimen current, transmitted electrons and light (cathodoluminescence) are some of the types of signals produced by an scanning electron microscope. It is rare that a single machine would have detector for all possible signals but secondary electron detectors are common in all scanning electron microscopes. The signals result from the interaction of the atoms at or near the surface of the samples with electron beams. In most common or standard detection mode, the SEM can produce very high resolution images of a sample surface revealing information and details about less than 1 to 5 nm in size. This is known as secondary electron imaging or SEI. SEM micrographs have a large depth of field yielding due to very narrow electron beam; a characteristic three dimensional appearance can be obtained which could be useful for understanding the surface structure of the sample.

The SEM test is conducted at SEM laboratory in the Metallurgical Department, NIT Rourkela using JEOL-JSM-6408LV SEM instrument. The figures of the four insulating sheet namely nomex, lather minilex, white minilex and glass cloth after the effect of impulse voltage was taken by SEM.

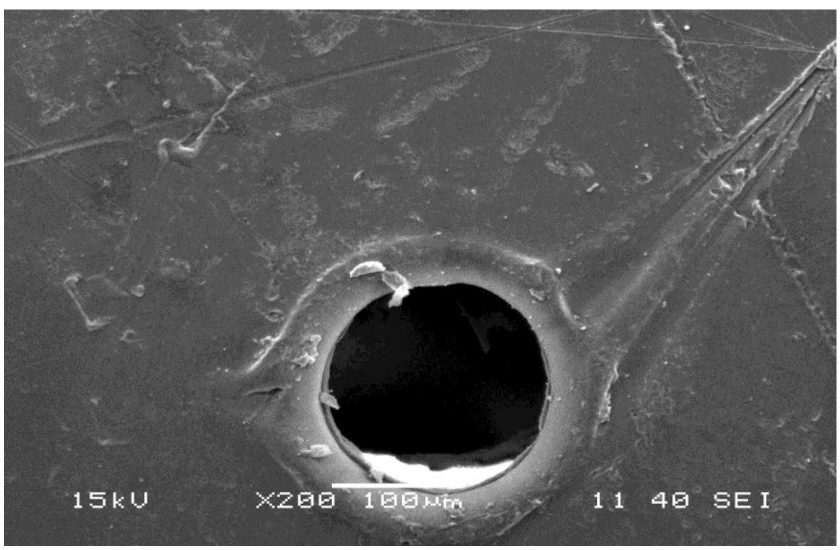
Fig 4.1 Scanning Electron Microscope

4.5 INTERPRETATION OF SEM IMAGES

The SEM images of the four insulating sheet namely Nomex, Glass cloth; Lather Minilex and White Minlex are discussed below.



(a)

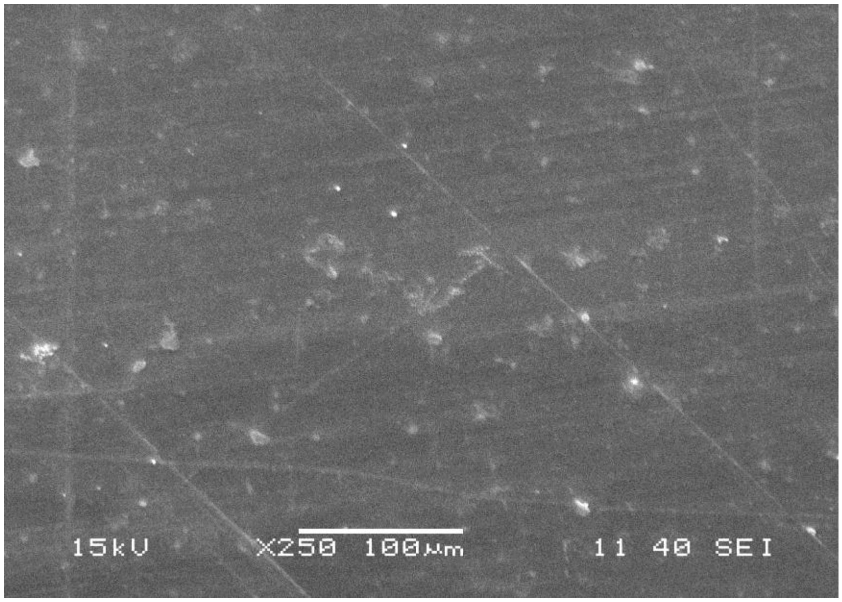


(b)

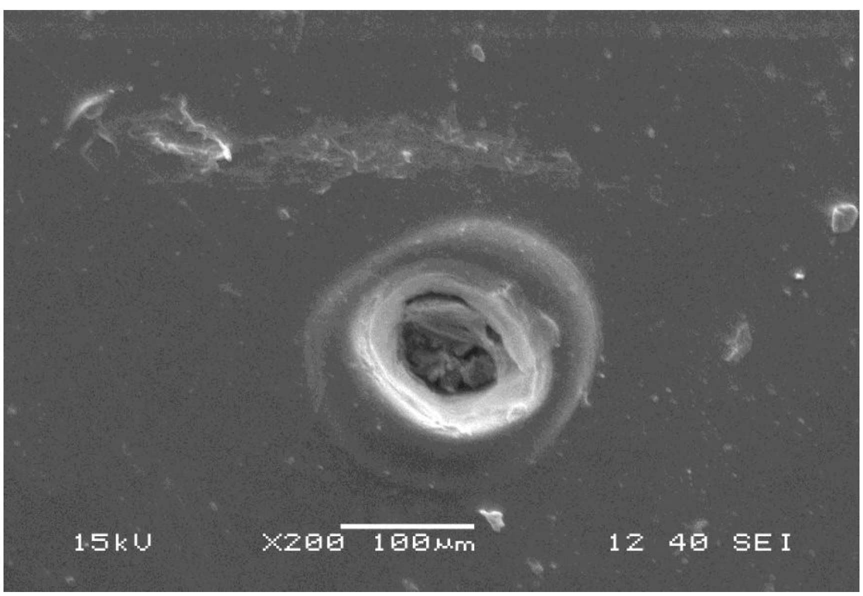
Fig 4.2SEM observation Of Lather Minilex Paper (a) Virgin sample(b) Stressed sample

Figure 4.2 shows the SEM observations for the (a) virgin samples of Lather Minilex paper. The breakdown of the sample took place at a voltage level of 78.01kV. The accelerated voltage of the scanning electron microscope was kept at 15kV and the vacuum level was 30Pa. The center of the lather minilex paper was magnified to 200 times. Figure (a) clearly shows the healthy sample of the lather minilex paper. Figure (b) shows the increased roughness of the sample with shallow cracks and some spots.

Figure 4.3 shows the SEM observations for the (a) virgin samples of White minilex paper. The breakdown of the sample took place at a voltage level of 80.34kV. The accelerated voltage of the scanning electron microscope was kept at 15kV and the vacuum level was 30Pa. The center of the White Minilex paper was magnified to 200 times. Figure (a) clearly shows the healthy sample of the White Minilex paper. Figure (b) shows the increased roughness of the sample with shallow cracks and some spots.

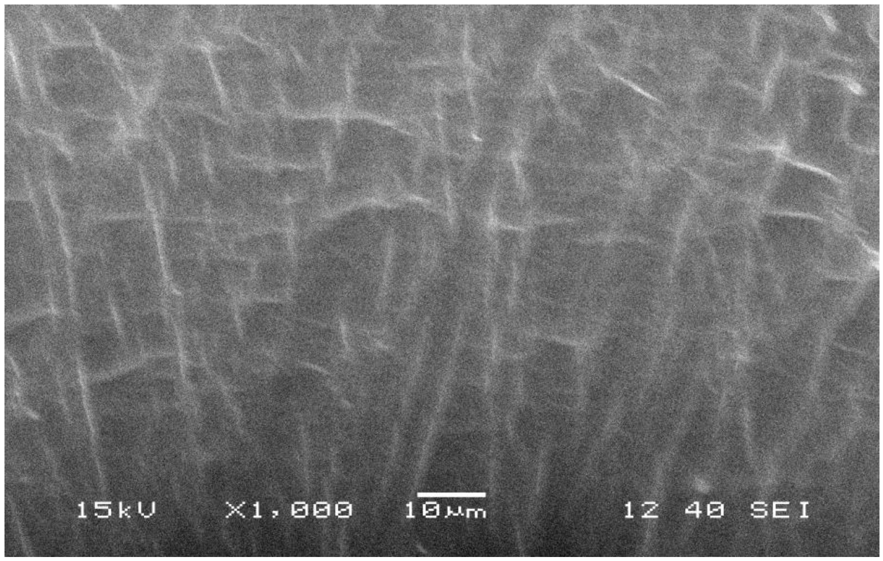


(a)

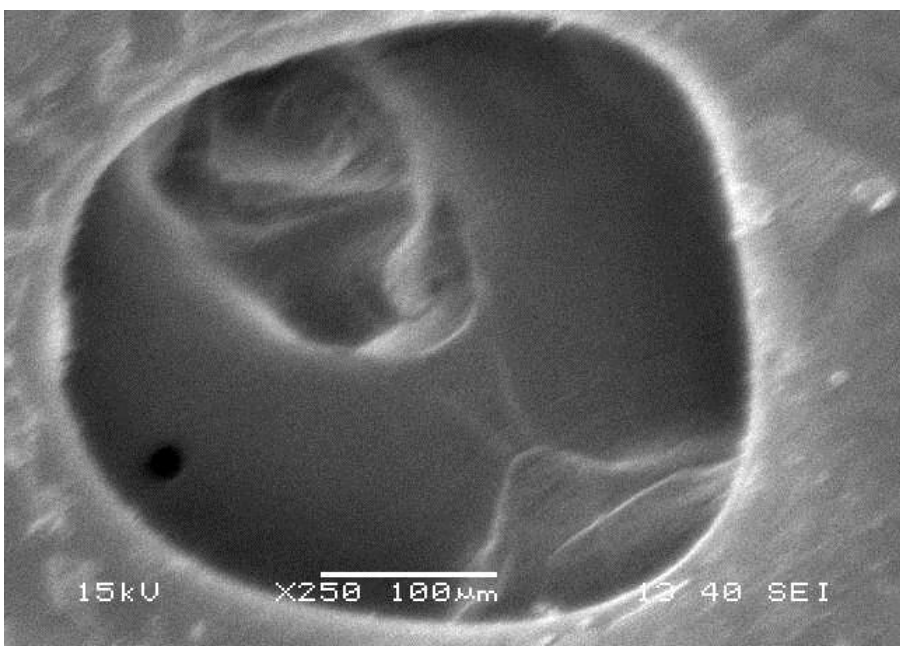


(b)

Fig4.3SEM observation Of White Minilex Paper (a) Virgin sample (b) stressed sample



(a)

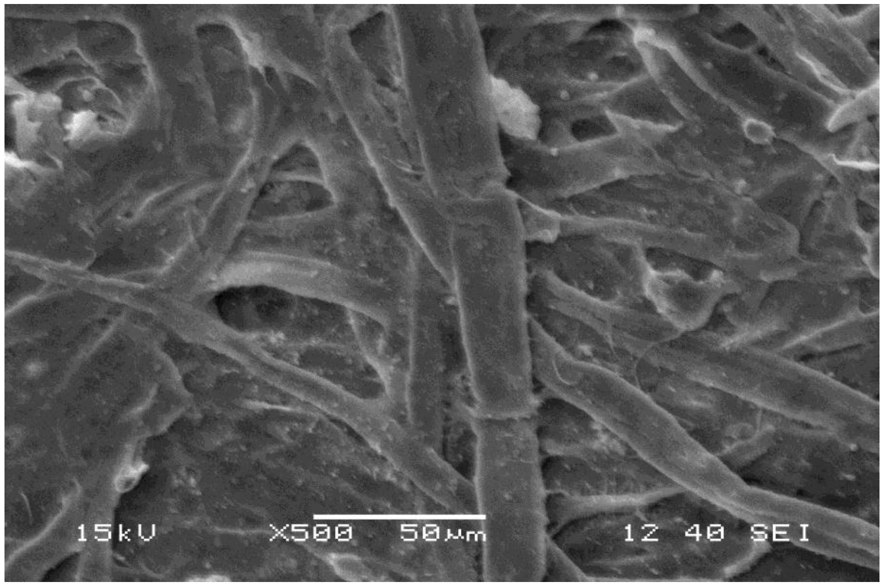


(b)

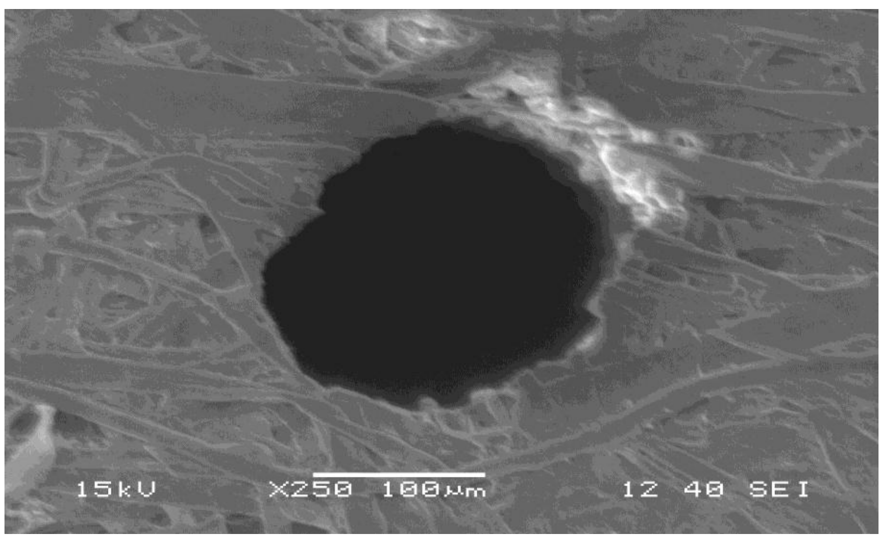
Fig4.4SEM observation Of Glass Cloth (a) Virgin sample (b) Stressed sample

Figure 4.4 shows the SEM observations for the (a) virgin samples of Glass Cloth paper. The breakdown of the sample took place at a voltage level of 78.01kV. The accelerated voltage of the scanning electron microscope was kept at 15kV and the vacuum level was 30Pa. The centre of the Glass Cloth paper was magnified to 250 times. Figure (a) clearly shows the healthy sample of the glass cloth paper. Figure (b) shows the increased roughness of the sample with shallow cracks and some spots.

Figure4.5 shows the SEM observations for the (a) virgin samples of Nomex paper. The breakdown of the sample took place at a voltage level of 80.34kV. The accelerated voltage of the scanning electron microscope was kept at 15kV and the vacuum level was 30Pa. The center of the Nomex paper was magnified to 250 times. Figure (a) clearly shows the healthy sample of the Nomex paper. Figure (b) shows the increased roughness of the sample with shallow cracks and some spots.



(a)



(b)

Fig 4.5SEM observation Of Nomex Paper (a) Virgin sample (b) Stressed sample

CHAPTER 5

RESULTS AND DISCUSSIONS

CHAPTER 5

RESULTS AND DISCUSSIONS

The effect of impulse voltage on various solid insulating materials like Nomex paper, Lather Minilex, Glass Cloth and White Minilex sheets was experimentally performed in the sphere - sphere electrode arrangement and experimental data was obtained. The graph was plotted for the breakdown voltage of insulating sheets against the thickness of the insulating sheet. On analyzing the graph 5.1(a) it was obtained that breakdown voltage for the various insulating sheet increases as the thickness of the material was increased. The graph is plotted for the gap distance of 0.5 c.m. The graph 5.1(b) was plotted for the same parameters and was inferred that Lather Minilex is better insulating material compared to the Nomex paper as the slope of the Lather Minilex was more than the Nomex paper slope. The graph 5.1(c) was plotted for the Glass cloth and White Minilex paper for the same parameter and was inferred that Glass cloth is better than White Minilex for insulating purpose at high voltage. The graph 5.1(d) was plotted for the parameter of breakdown voltage and gap geometry of the electrode. The thickness of the material was 5 mm for all material. On analysis of the graph 5.1(d) it was inferred that breakdown voltage of the insulating sheet increases as the gap distance is increased. The graph 5.1(e) was plotted for the same parameter for Nomex, Lather Minilex and Glass Cloth. The graph 5.1(f) was plotted for same parameter for lather minilex, glass cloth and white minilex .The graph 5.1(g) was plotted for same parameter but the thickness of all the material was kept 7mm.

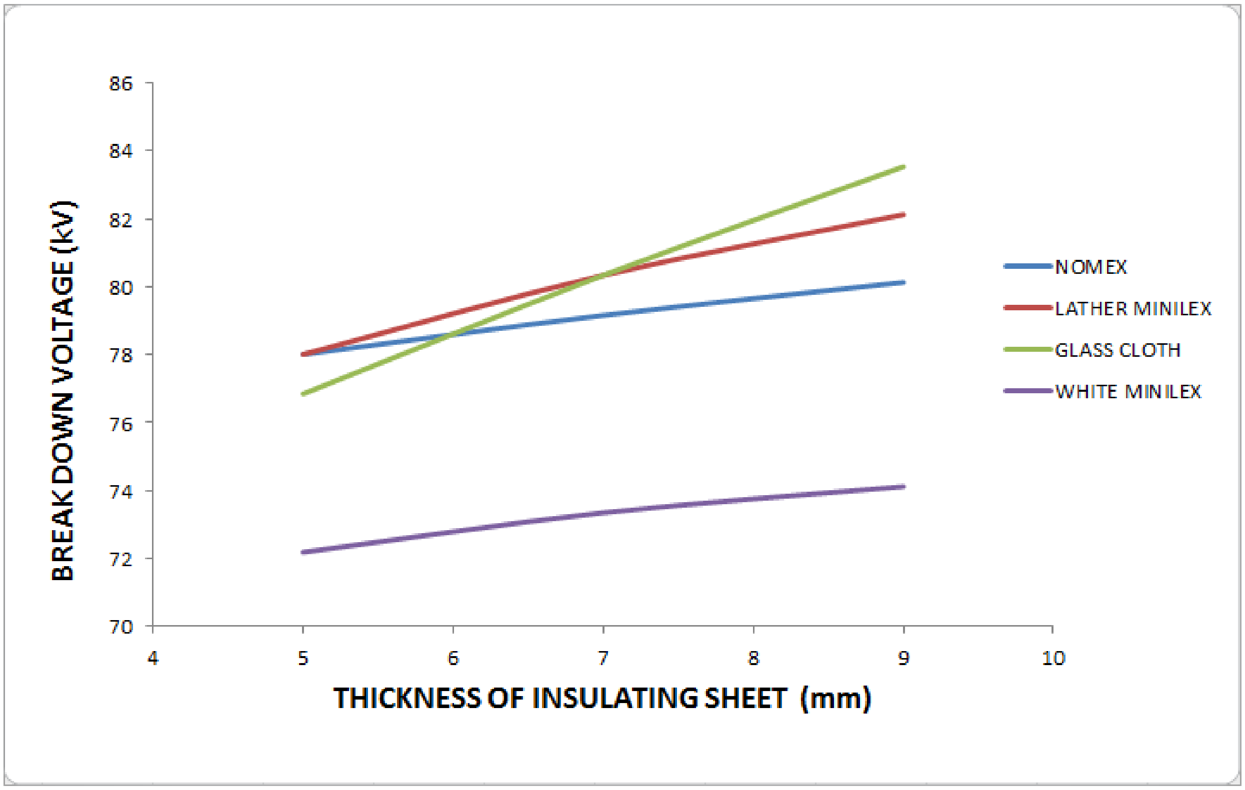


FIG 5.1(a). Variation of Breakdown Voltage with Thickness of insulating sheets.

Graph 5.1(a) shows the curve variation for the breakdown voltage with the thickness of the material for all insulating sheets namely Glass Cloth, Nomex, White Minilex and Lather Minilex paper. From the graph it is clear that as the thickness of the glass cloth increases there is a considerable increase in its breakdown voltage. Nomex insulating sheet has the breakdown voltage lower than the Glass Cloth and Lather Minilex while White Minilex has the lowest breakdown voltage among the all insulating sheets.

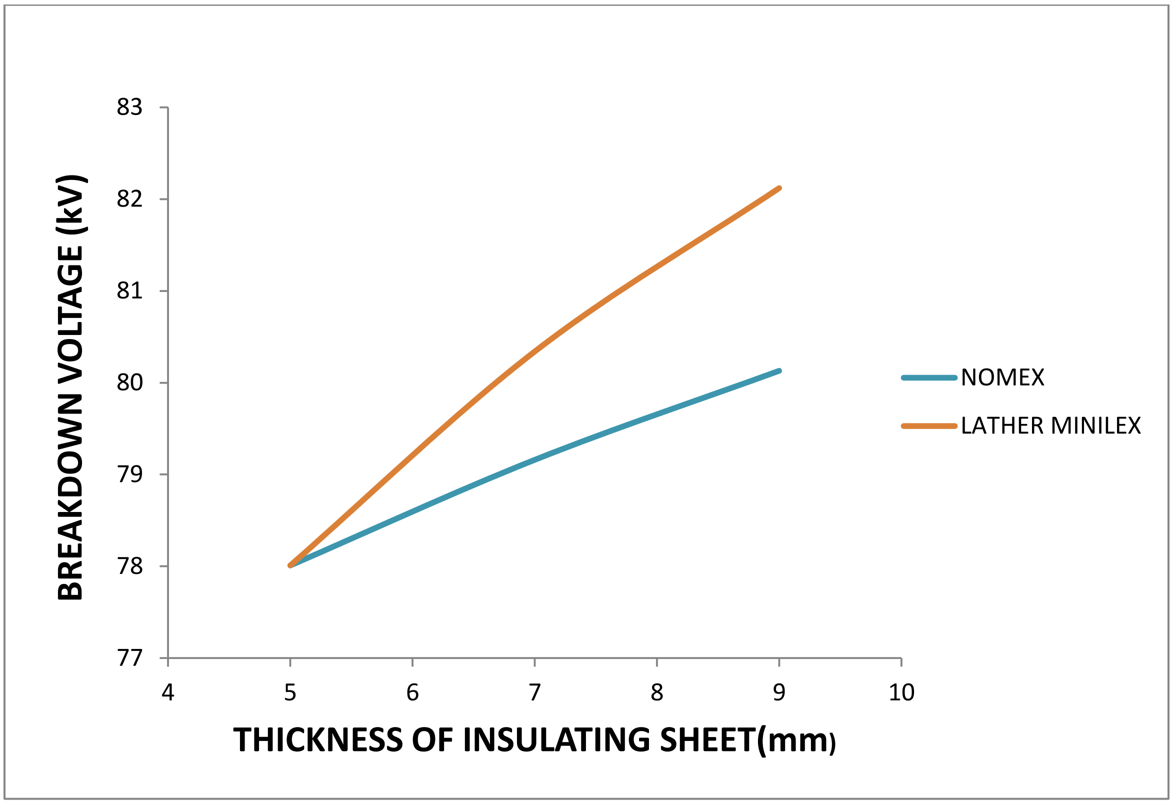


FIG 5.1(b). Variation of Breakdown voltage with thickness of insulating sheet for Nomex and Lather Minilex.

Graph 5.1(b) shows the comparison of the breakdown voltage with thickness of the insulating sheet for Nomex and Lather Minilex.The curve variation clearly shows that Lather Minilex is better insulating material at high voltage than the Nomex insulating sheet.

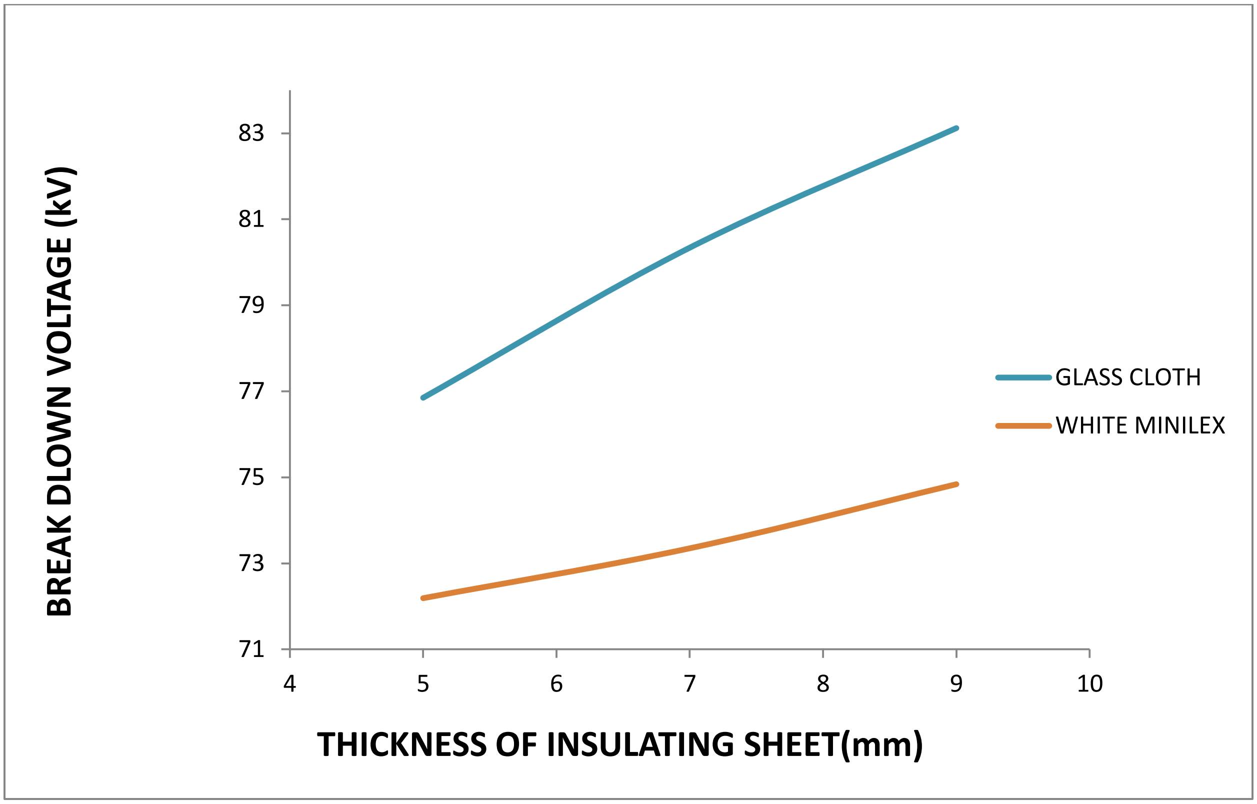


FIG 5.1(c) Variation of Breakdown Voltage with thickness of insulating sheet for Glass Cloth and White Minilex.

Graph 5.1(c) shows the comparison of the breakdown voltage with thickness of the insulating sheet for Glass Cloth and White Minilex.The curve variation clearly shows that Glass Cloth is better insulating material at high voltage than the White Minilex insulating sheet as the slope of Glass Cloth is more than the White Minilex.

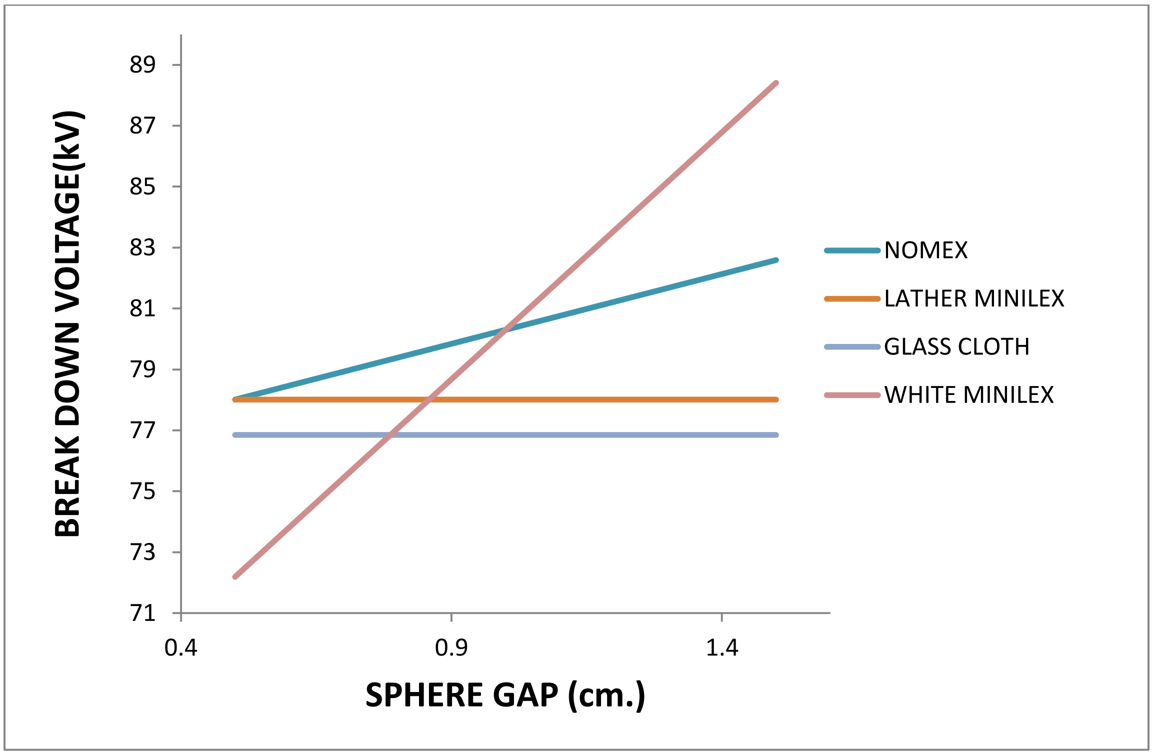


FIG 5.1(d) Variation of Breakdown Voltage with Gap Geometry of Sphere-Sphere Electrode for Nomex, Lather Minilex, Glass Cloth and White Minilex.(5 mm thickness).

The graph 5.1(d) shows the variation for the breakdown voltage of the insulating sheet with gap geometry of the electrode sphere. From the graph it is clear that as the gap distance of the sphere electrode increases the breakdown voltage of the solid insulating material increases.The graph shows the variation of breakdown voltage of solid insulating material with gap geometry for all the insulating sheets keeping thickness 5 mm.

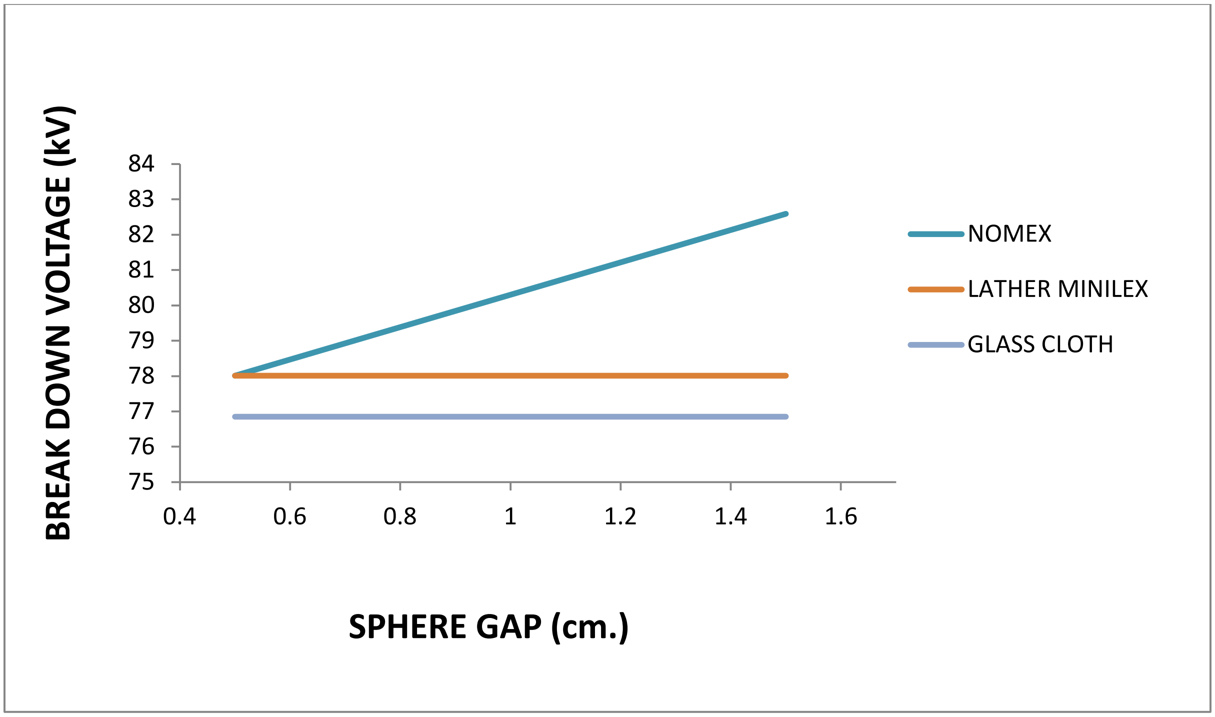


FIG 5.1 (e) Variation of Breakdown Voltage with Gap Geometry of Sphere-Sphere Electrode for Nomex, Lather Minilex and Glass Cloth.

The graph shows the variation of the breakdown voltage of the solid insulating sheet with gap geometry of the electrode for Nomex, Lather Minilex and glass cloth. The graph clearly shows that Nomex has better insulating property than Lather Minilex and glass cloth when the thickness of entire insulating sheet was kept 5 mm.

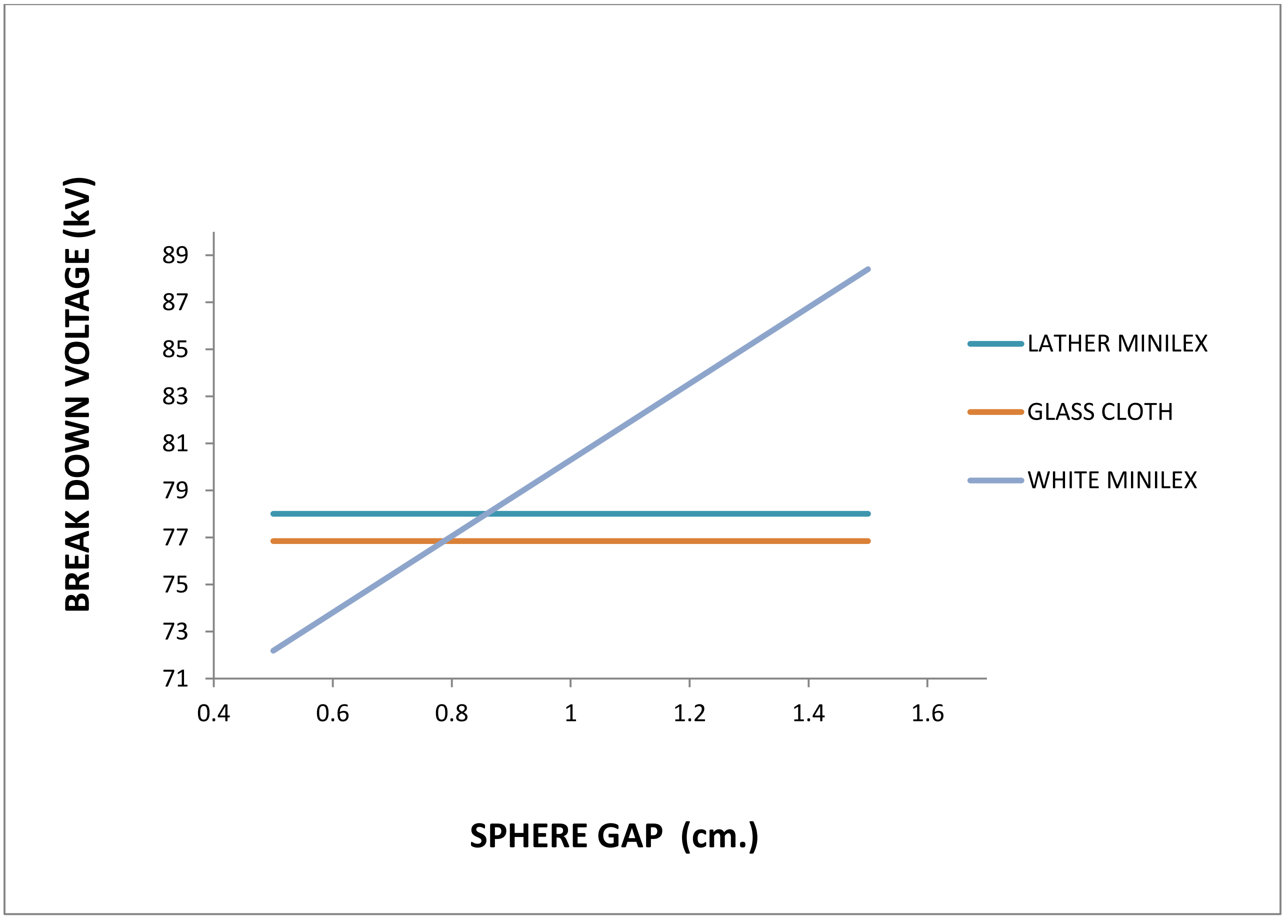


FIG 5.1(f). Variation of Breakdown Voltage with Gap Geometry of Sphere-Sphere Electrode for Lather Minilex, Glass Cloth and White Minilex.

The graph shows the variation of the breakdown voltage of the solid insulating sheet with gap geometry of the electrode for White Minilex, Lather Minilex and Glass Cloth. The graph clearly shows that Lather Minilex has better insulating property as its slope is greater than white minilex and glass cloth when the entire thickness of the insulating sheet was kept 5 mm.

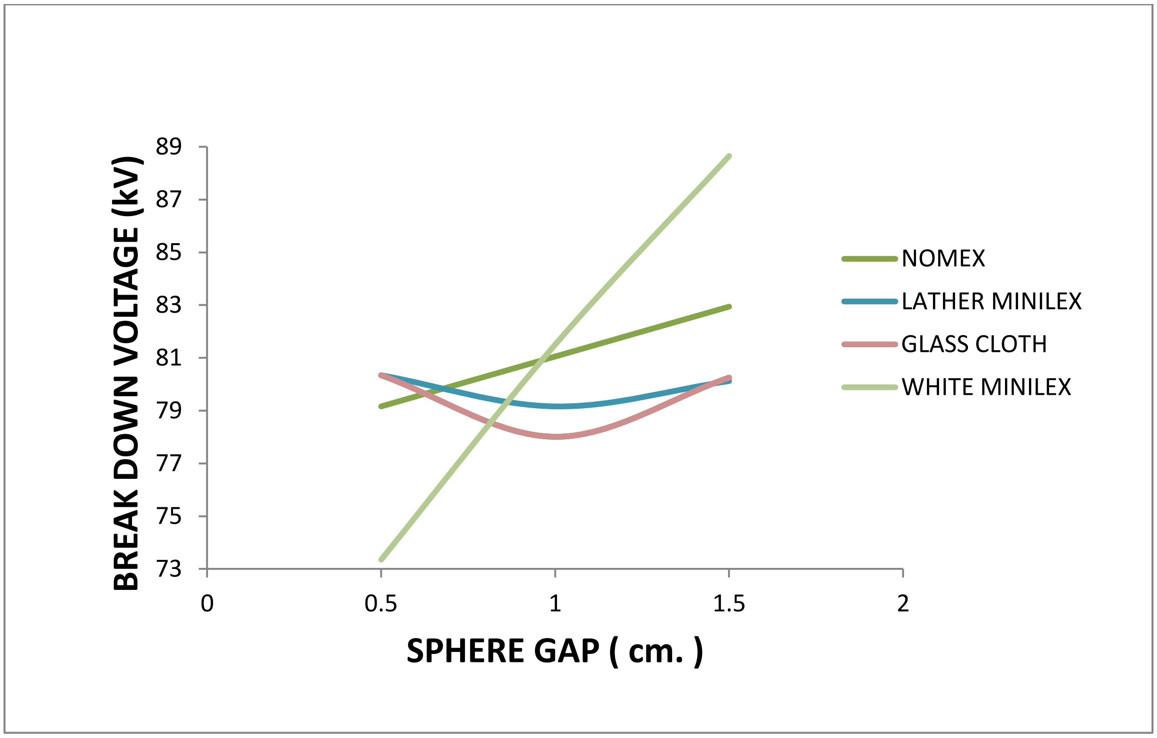


FIG 5.1(g).Variation of Breakdown Voltage with Gap Geometry of Sphere-Sphere Elecrode for Nomex,Lather Minilex, Glass Cloth and White Minilex(7 mm thickness).

Graph 5.1 (g) shows the curve variation for the breakdown voltage with gap geometry of the sphere- sphere electrode arrangement for Nomex, Glass Cloth, White Minilex and Lather Minilex when thickness of the entire insulating sheet was kept 7mm.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE OF WORK

CHAPTER-6

CONCLUSIONS AND FUTURE SCOPE OF WORK

6.1 CONCLUSION

It becomes necessary for the todays electrical engineers to know various types of solid insulations and their properties in order to economize the cost applications and keeping safety considerations on the other hand. One of the main problems of the high voltage engineering is the degradation of the insulation of the solid insulating material. It has been revealed through the several research and studies. As the high voltage power equipment are directly and mainly subjected with the spark over voltage caused by impulse voltage like lightening strokes and switching action. The sphere-sphere electrode arrangement is mainly used for the measurement of the peak values of the high voltages as adopted by the IEC and IEEE. Generally in the electrical power equipment, the standard sphere gaps are widely used. The effect of the impulse voltage on different insulations like Nomex,Lather Minilex,White Minilex and Glass cloth has been studied. To study and observe the effect on insulation of the solid material due to breakdown mechanism, the insulation samples are collected after the application of the impulse voltage test and analysis is done with the help of scanning electron microscope (SEM).A standard sphere of 25cm in diameter is used to measure the effect of impulse voltage. Finally the experimental data is generated and compared with the theoretical and the graphical interpretation is done. Hence the determination of the breakdown voltage of various insulating material gives a major area of interest to the electrical engineers and in particular to the high voltage engineers. Therefore, the possibility of developing solid insulating materials with excellent breakdown strength is viable through study and research.

6.2 FUTURE SCOPE OF THE WORK

The present research work is focused on the experimental validation of the breakdown characteristics in high voltage test laboratory of the solid insulating material like Lather Minilex, Glass Cloth, White Minilex and Nomex paper and comparison is made with the theoretical calculations. The complete analysis provides an analytical framework for designing the withstand capacity of the high voltage insulation systems. This study can be extended for analyzing breakdown and pre-breakdown strength of the solid insulating material and the performance characteristics for measuring AC, DC and impulse voltages. This work also gives the future work opportunity using different types of electrodes (i.e., needle-plate, plate-plate, needle-sphere, rod-rod etc.).

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